

Fundamentals of electromagnetic energy transfer

Discussion of some weaknesses in the traditional approach to e.m. theory, and the establishment of a sounder foundation

by Ivor Catt.

The rise of digital electronics has highlighted weaknesses in our approach to the fundamentals of electromagnetic theory. This paper discusses some of the weaknesses and begins the building of a more sound approach at the fundamental level.

In the 1870s Oliver Heaviside, the father of digital electronics, worked with his brother Arthur to improve pulse signalling down a transmission line, using theory and experiment to improve the performance of the undersea telegraph line between Newcastle and Denmark. This practical experience gave him a mastery of electromagnetic theory which remained unequalled for a century. It led to his greatest achievement, the discovery of the concept of 'energy current'^{1,2,3}, which he himself undervalued, and

SEPTEMBER 1984

never mentioned again after Hertz demonstrated the more glamorous wireless waves ten years later.

Ever since its advent in around 1900, wireless signalling has been regarded as a major advance. In fact, it stunted theoretical development. Wireless is a resonant, neo-steady state activity. It is far less central to the successful development of electromagnetic theory than its apparent primitive precursor, the TEM step or transient, travelling undistorted at the speed of light, guided by two conductors. The glamour, the magical nature of signalling without wires caused the suppression and then the loss of understanding of the mechanism by which a pulse travels at the speed of light from one logic gate to the next. In 1949, this suppression even made it possible for Albert Einstein to dismiss the

very idea of a logic pulse as absurd!

"...If I pursue a beam of light with the velocity c (velocity of light in a vacuum), I should observe such a beam of light as a spatially oscillatory electromagnetic field at rest. However, there seems to be no such thing, either on the basis of experience or according to Maxwell's equations." (ref.4)

A deep chasm developed between the post Einstein Community, who call themselves 'modern physics', and digital electronic engineering, the latter being based on the logic pulse which the former dismissed as absurd. (Within the 'modern physics' community, the only viable electromagnetic wave is the sine wave, whereas digital electronics is based on the pulse^{3,5}.)

Einstein never read Heaviside, and Heaviside, although very interested in Einstein, lacked the information needed to grasp the nature of the gaffe Einstein had committed. Today, the chasm could be bridged if only professors of modern physics would look at high-speed logic pulse using a sampling oscilloscope⁵. They would then be forced to admit that, far from being absurd, Heaviside's slab of energy current exists.

"Thus the whole slab moves bodily to the right at speed v , so that a moves to A and b moves to B in the time given by $vt = aA$ or bB .

"The disturbance transferred in this way constitutes a pure wave. It carries all its properties unchanged...

in the same way, all moving along independently and unchanged.

"... Since every slab is independent of the rest, there need be no connection between the directions [—polarity, sign,] of E in one slab and the next. The direction may vary anyhow along the wave."³

Since Einstein went on to say that the false statement of his is the very basis of relativity, we can see why 'modern physics' contributes no help, but only confusion, to the work of computer designers.

Energy current

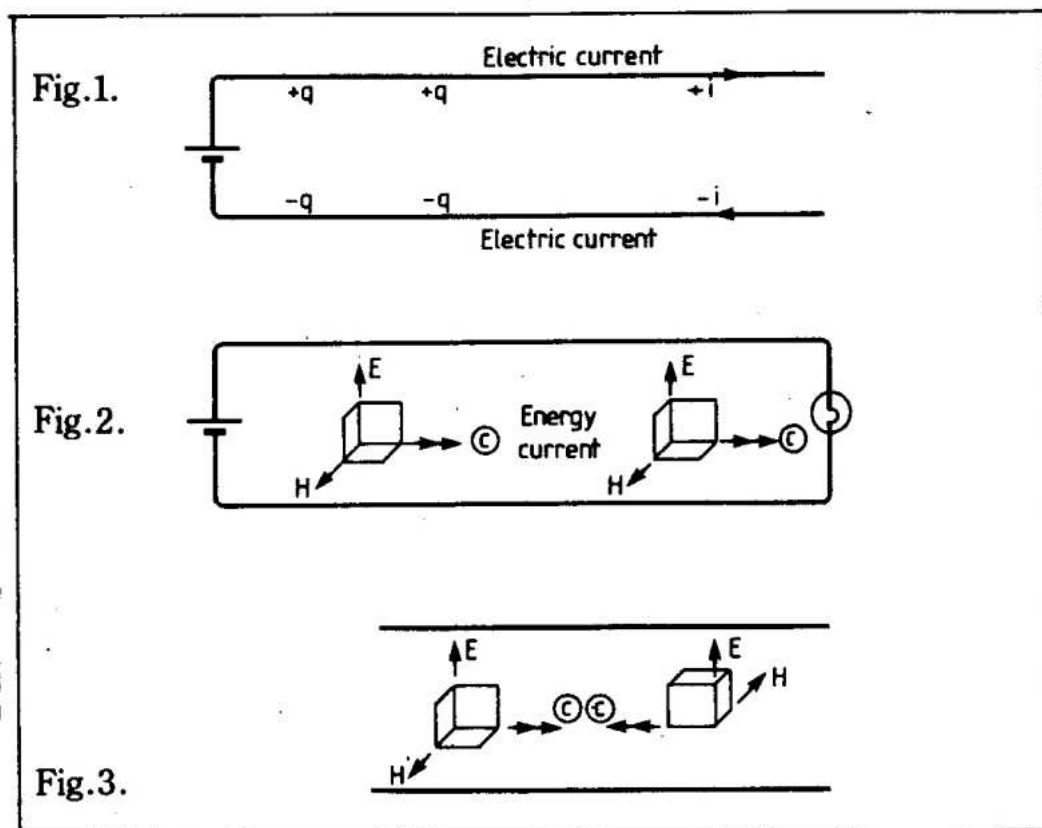
Whereas the conventional approach to electromagnetic theory is to concentrate on the electric current in wires, with some additional consideration of voltages between the wires, Heaviside concentrates primarily on what he calls 'energy current, this being the electromagnetic field which travels in the dielectric

between the wires. It has an amplitude equal to the Poynting Vector, $E \times H$. Heaviside's phrase, "We reverse this"; points to the great watershed between the 'etherials' who with Heaviside believe that the signal is an 'energy current' which travels in the dielectric between the wires, and the 'practical electricians', who like Sprague believe that the signal is an electric current which travels down copper wires, and that if there is a 'field' in the space between the wires, this is only a result of what is happening in the conductors¹.

Fig.1. Theory N. Electric current is the cause.

Fig.2. Theory H. Energy current is the cause.

Fig.3. Trapped energy current.



Oliver Heaviside announced Theory H a century ago².

"Now in Maxwell's theory there is the potential energy of the displacement produced in the dielectric parts by the electric force, and there is a kinetic or magnetic energy of the magnetic induction due to the magnetic force in all parts of the field, including the conducting parts. They are supposed to be set up by the current in the wire. We reverse this; the current in the wire is set up by the energy transmitted through the medium around it..."

The importance of Heaviside's phrase, "We reverse this", cannot be overstated. (See Fig. 1, Fig. 2.) It points to the great watershed between the 'practical electricians'^{7,8}, who have held sway for the last half century, promulgating their theory — which we shall call 'Theory N', the Normal theory: that the cause is electric currents in wires and electromagnetic fields are merely an effect — and the 'etherials', who believe what we shall call 'Theory H': that the travelling field is the cause, and electric currents are merely an effect of this field.

The 'energy current' approach, Theory H, is much the

more helpful approach for the digital designer. The car battery delivers energy which is guided between the 0V and +12V lines, to the car headlight. The electromagnetic energy travels down through the dielectric at the speed of light.* When the energy reaches the lamp, it penetrates into the filament, is absorbed and converted.

If the car lamp is removed, the energy current reflects at the resulting open circuit and returns back towards and into the battery, always travelling at the speed of light. This results in an endless dance of energy. The energy current continually flows from the battery at the speed of light; reflects at the open circuit to the right; and flows back into the battery, there to reflect back out again from the (left hand) far end of the battery plates and down between the wires for a second time.

In the resulting, apparently stationary, quiescent state, there is no mechanism for the energy current, which has been delivered into the dielectric between the wires at the speed of light, ever to slow down as it oscillates from end to end.

If the two wires are now suddenly cut at the middle, then energy current (conventionally thought to be electric charge) is

*The density of this energy at any point is equal to the product of the electric field D and the magnetic field B , which are always at right angles to each other and to the direction of energy flow. The flow rate of energy across unit area is $E \times H$, which is called the Poynting Vector.

trapped between the wires to the right. The energy is apparently stationary, but in fact is all moving at the speed of light. If these wires were very wide and close, we would have a conventional charged capacitor. At any moment, half of the energy trapped in a charged capacitor is moving to the right, and the other

half if moving to the left. Using either theory N or H^8 , the total current in each plate (or wire) is zero, so there are no i^2R losses, only dielectric leakage G losses, which would be zero in the case of a vacuum dielectric. Attempts to detect the magnetic field component of the energy current would be frustrated by the fact that the leftwards travelling energy current has a magnetic field component in the opposite direction to that of the rightwards travelling energy current^{9,10} (Fig.3).

Nature of space and ether

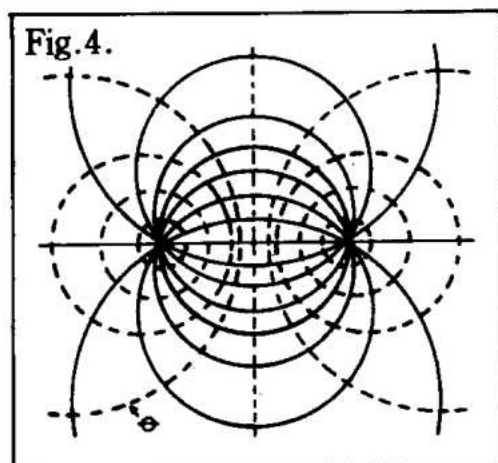
A logic pulse is a TEM wave (Transverse Electromagnetic Wave), which means that both the electric field and the magnetic field are at right angles to the direction of propagation. Also, at every point, the electric field and the magnetic field are at right angles to each other. If the wires in Fig.2 are circular, the field pattern is as in Fig. 4.

The vertical E lines and the circular H lines divide the surface into what are called 'curvilinear squares' of equal width and

height. Down one side of a square the electric potential drop is E and along the other side the magnetic potential drop is H . If the dielectric medium has permittivity ϵ and permeability μ then the ratio of E to H is $E/H = \sqrt{\mu/\epsilon}$, which in the case of a vacuum dielectric turns out to be 377 ohms. Further, the velocity of propagation of this energy current into the paper is equal to $1/\sqrt{\mu\epsilon}$ which in the case of a vacuum turns out to be 300,000 km per second.

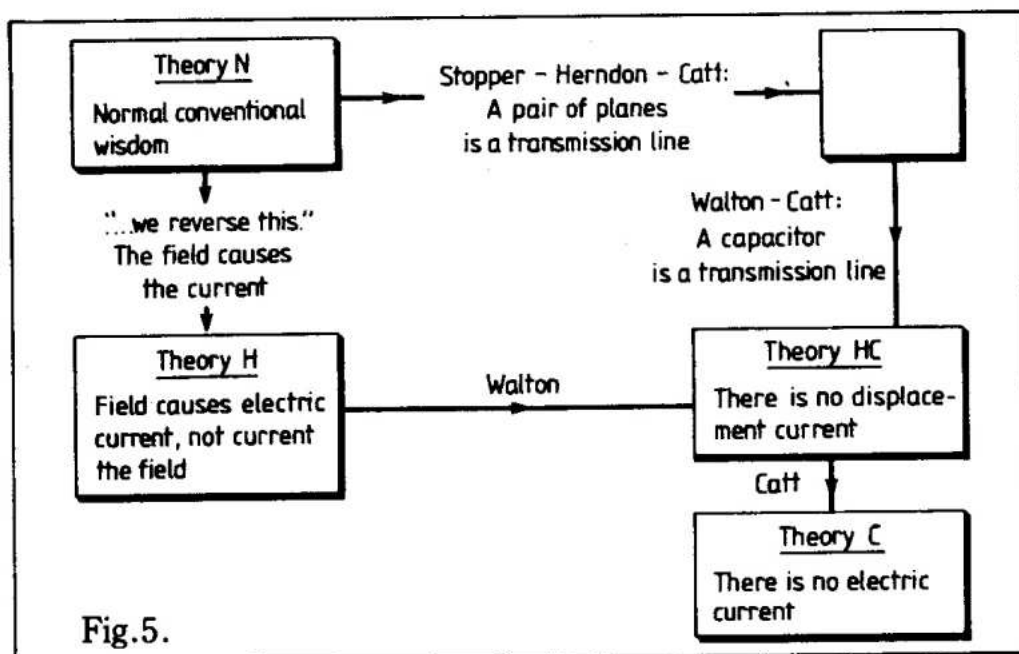
(It is noteworthy that Einstein himself and also the whole post-Einstein community who call themselves 'modern physics', never mention the impedance of free space $\sqrt{\mu/\epsilon}$, although it is one of the key primitives on which digital electronic engineering is based. The reader is encouraged to look for reference to it in the literature of modern physics.)

Fig.4. Curvilinear squares.



As energy current flows through one of the squares in the (vacuum) dielectric in Fig. 4, it is resisted in its attempt to proceed. This is necessary, because if energy is flowing through the square, work must be done. The $E \times H$ energy works against the impedance of the square surface, 377 ohms, as it passes through that surface. The resistance (impedance) of a square of vacuum is innate. Thus, empty space has

Fig.5. The theories.



the physical characteristic, impedance (resistance), a fact which has to be ignored in modern physics which conforms to the belief that empty space has no features. (It is remarkable that, while ignoring $\sqrt{\mu/\epsilon}$, modern physics can still make such play with velocity, $1/\sqrt{\mu\epsilon}$.)

In the world view of the digital electronic engineer, it is convenient to say that free space and the ether are synonymous. This includes the assertion that the ether exists; it is the something which resists the passage of energy and so, paradoxically, makes the passage of electromagnetic energy $E \times H$ possible. (It is impossible to give kinetic energy to a brick with zero mass. Similarly, it is impossible to deliver potential energy to a spring whose Young's Modulus is either zero or infinity. Energy may only enter a region when its entry is reasonably resisted — hence the need for free space to have an impedance (resistance), if energy is to be able to enter it.)

Via a devious route, we have come to think that the fundamental primitives in a region of space are permittivity and permeability, ϵ and μ . However, when it comes to actually measuring anything, which mean measuring the impedance (of space) or the velocity (of space), we find that we always use ϵ and μ in combination in order to form velocity \odot or impedance Z_0 . It seems clear that the latter two are more primi-

tive, being more fundamental and also measureable, and ϵ and μ are merely subsidiary parameters lacking fundamental physical reality. To sum up; whereas it is usual to start with ϵ and μ and derive the impedance $Z = \sqrt{\mu/\epsilon}$ and velocity $\odot = 1/\sqrt{\mu\epsilon}$, it is more correct to start with Z and \odot , the directly measurable parameters of a region of space.

Should we be so disposed, we could then derive ϵ and μ using the formulae $\epsilon = 1/Z\odot$ and $\mu = Z/\odot$. However, although being far divorced from physical reality, ϵ and μ remain useful instruments for use in calculation.

(A further advance which the reader might wisely ignore initially is made when we realise that length of a region of (single velocity) space and velocity of propagation through that region cannot be independently measured. All that we can measure is the time delay through that region. We should move to the idea of a segment of space being of length t , e.g. 1 n, rather than of length 1 foot¹¹.) \searrow 1 nsec

Theories

A number of different dualisms obtain within or in the vicinity of electromagnetic theory as it is developing. The student needs to be warned against thinking that only one dualism is involved, and that he is merely seeing different expressions of the same dualism.

Fig.6. Two voltage planes act as transmission line.

The mutually distinct dualisms include:

wave-particle dualism

Theory N — Theory H⁸

The Rolling Wave — The Heaviside signal¹⁹

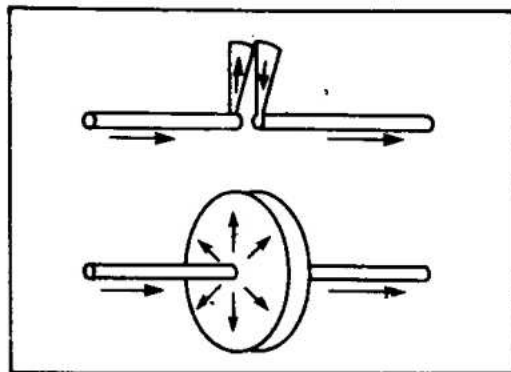
It will be seen later that one of these is in fact a three-way split between Theory N, Theory H and Theory C.

Historical development. The transition from classical, wireless-based electromagnetic theory, loosely equivalent to Theory N⁸, to one of the preferred theoretical positions for the digital electronic designer, Theory H or Theory C⁸, is via a complex development shown in Fig. 5.

The capacitor

In the early 1960's I pioneered the inter-connection of high speed (1 ns) logic gates at Motorola, Phoenix, Arizona¹². One of the problems to be solved was the nature of the voltage decoupling at a point given by two parallel voltage planes. I asked Bill Herndon about this problem, and he gave me the answer: "It's a transmission line"¹³. Bill learnt this from Stopper, whom I never met, who now works for Borroughs in Detroit.

The fact that parallel voltage planes, when entered at a point,



present a resistive, not a reactive, impedance, was for me an important breakthrough. (It meant that as logic signal speeds increased, there would be no limitation presented by the problem of supplying +5V.). The reader should be able to grasp the reason why voltage plane decoupling is resistive by studying Fig. 6, which shows the effect of a segment only of two planes as they are seen from a point¹⁴.

During the next ten years, with the help of Dr D.S. Walton, I gradually came to appreciate that, since a conventional capacitor was made up of two parallel voltage planes it also had a resistive, not a reactive (i.e. capacitive or inductive) source impedance when used to decouple the +5V supply to logic. Since the source impedance (= transmission line characteristic resistance) is well below one ohm, the transient current demand of logic gates approaching infinite speed can still be successfully satisfied with +5V from a standard capacitor of any type¹⁵. (The reason why the myth has developed that the worst (low capacitance, 'r.f.') capacitors are the best in this role is discussed elsewhere¹⁶).

The capacitor is an energy store, and when energy is injected, it enters the capacitor sideways at the point where the two leads are joined to the capacitor. Nothing ever traverses a capacitor from one plate to the other. This is clearly understood in the case of a transmission line. By definition, when a TEM wave travels down a transmission line,

nothing travels sideways across the transmission line, or we would not have a transverse electromagnetic wave.

Spring cleaning

"Then there were the remarkable researches of Faraday, the prince of experimentalists, on electrostatics and electrodynamics and the induction of currents ... The crowning achievement was reserved for the heaven-sent Maxwell, a man whose fame, great as it is now, has, comparatively speaking, yet to come"¹⁷

"Now, there are spots on the sun, and I see no good reason why the faults in Maxwell's treatise should be ignored. It is most objectionable to stereotype the work of a great man, apparently merely because of the great respect thereby induced..."¹⁸

"Heaviside, seventy years ago, missed the key point by a whisker. He failed, but he failed gloriously. He never discovered the flaw in the structure, displacement current."¹⁹

"Heaviside put together the main features of the new concept, but it took another century to put flesh on to the bare bones."²⁰

"Closely related is Heaviside's concept of an electromagnetic wave, which in principle does not undulate, but only propagates itself. This concept leads to interesting insights which have not yet been fully realised. ... Many questions concerning this concept exist which, as Heaviside said, 'Have still to be worried about.'²¹

The Catt anomaly

Until recently, the only flaws in classical electromagnetism were

shown up by the new theoretical discoveries indicated in Fig.5. However, more recently, thanks to Dawe²², I have been led to a flaw at a more simplistic level. We shall deal with this flaw, called the 'Catt Anomaly', first.

Traditionally, when a TEM step (i.e. a logic transition from low to high) travels through a vacuum from left to right, (Fig.7.), guided by two conductors (the signal line and the 0V lines), there are four factors which make up the wave:

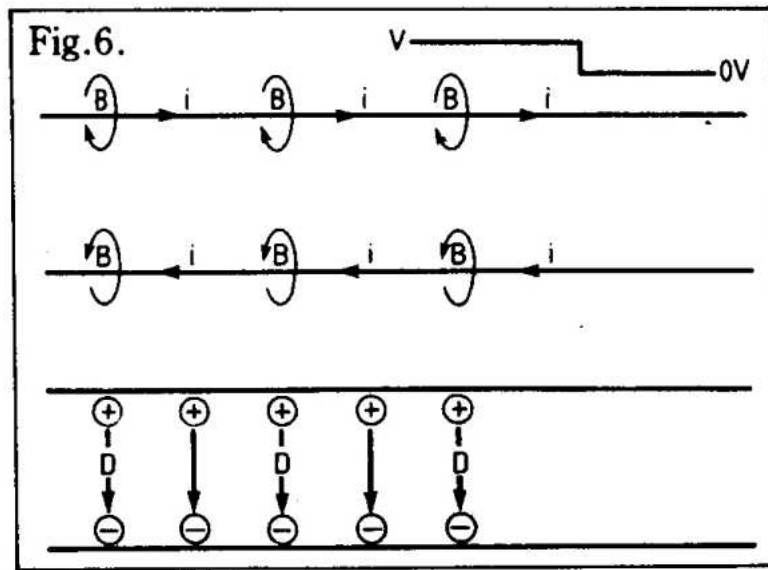
- electric current in the conductors;

- magnetic field, or flux, surrounding the conductors;

- electric charge on the surface of the conductors;

- electric field, or flux, in the vacuum terminating on the charge.

Fig.7. Four factors in a TEM wave.



The key to grasping the anomaly is to concentrate on the electric charge on the bottom conductor.

During the next 1 nanosecond, the step advances one foot to the right. During this time, extra negative charge appears on the surface of the bottom conductor in the next one foot length, to terminate the lines (tubes) of electric flux which now exist between the top (signal) conductor and the bottom (0V) conductor.

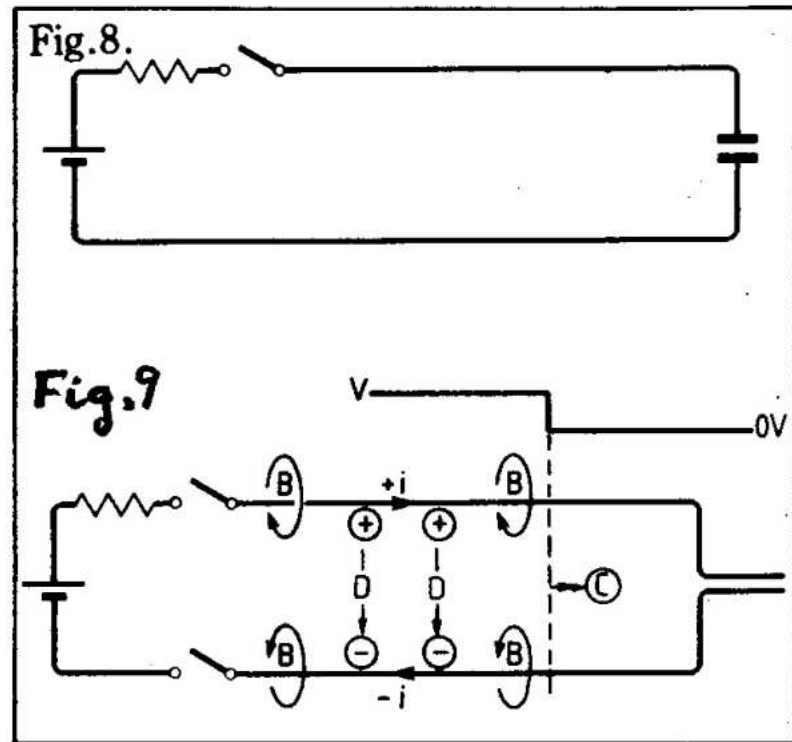
Where does this new charge come from? Not from the upper conductor, because by definition, displacement current is not the flow of real charge. Not from somewhere to the left, because such charge would have to travel at the speed of light in a vacuum. (This last sentence is what those "disciplined in the art" cannot grasp, although, paradoxically, it

is obvious to the untutored mind.) A central feature of conventional theory is that the drift velocity of electric current is slower than the speed of light.

Displacement current and the TEM wave. The concept of the transmission line and the TEM wave came after Maxwell's time, so he could not use it to resolve the anomaly which dogged electromagnetic theory in the mid-nineteenth century. This anomaly arose from consideration of the performance of the capacitor in a closed electric circuit, which upset the techniques which have been developed to relate electric current to nearby magnetic field. These were the Biot-Savart Law, $H = \frac{i \, dl \, \sin \theta}{4 \pi r^2}$ and Ampere's Rule,

$\oint H dl = i$. To resolve the anomaly, Maxwell proposed that the build-up of electric flux $\epsilon dE/dt$ (i.e. dD/dt) across the plates of a capacitor

Fig.8. The problem Maxwell faced.



behaved just like real electric current in that it generated magnetic flux nearby as per the Biot-Savart Law. However, the assumption underlying the anomaly which he purported to solve was as follows. In a closed circuit (Fig.8) comprising battery, resistor and capacitor, at the moment the switch is closed, electric current instantaneously flows in all parts of the circuit, including the capacitor.

Since Maxwell's time, we have learnt that there is no instantaneous action at a distance, and part

of that body of knowledge is the TEM wave which travels at the speed of light. We, who follow in the wake of the telegraph equations and the development of the TEM wave in a transmission line, know that when we close the switch(es), (Fig.9.) the current and field move across from left to right at the speed of light. We also know that the capacitor is merely a change in the characteristic impedance of the transmission line, and that the wave front enters it sideways.

Maxwell's difficulty with the anomaly disappears, and his fudge factor, displacement current, traversing the capacitor from top to bottom and creating magnetic field in the horizontal, forward, direction, becomes an embarrassment because by generating forward magnetic flux (which is why Maxwell invented it,) it contravenes the requirements of a TEM wave, that all magnetic field should be transverse. Once it is realised that a capacitor is a transmission line²³, we have to conclude that the traditional treatment of the capacitor (i.e. displacement current, generating forward magnetic flux) is incompatible with the traditional treatment of the transmission line (i.e. the TEM wave). We are forced to remove the concept of displacement current from our theory to prevent it from undermining the important concept of the TEM wave.

Repeated LC model for transmission line.

It is traditional to offer the LC model (Fig.10) as a good way of understanding the operation of a transmission line, with inductors either in the top line or in both lines. This is a disastrous model for a number of reasons: the series L induces the student to think that a lossless transmission line has a high frequency cut-off, which is untrue; it outlaws the possibility of signalling in both

directions at the same time, and is largely to blame for the general tendency to only half-use the capacity of long, expensive lengths of coax. or twisted pair cables; my erstwhile co-author Malcolm Dividson has pointed out that since a capacitor is a transmission line, the model is absurd — modelling something in terms of itself.

My erstwhile co-author Dr D.S. Walton has proposed a new model (Fig10), for the lossy transmission line, where losses R and G remain as discrete resistors periodically along the length, but each section is a delay unit with a certain characteristic impedance (i.e. resistance). According to this model, a signal passes alternately through resistive loss segments R—G, and delay segments. There are no reactive components. Dispersion will arise from repeated partial two-way reflections at each R—G element, and will of course be more apparent for 'high frequencies'.

Displacement current

I have argued that free space had at least one innate characteristic — impedance. In this section, written by F. David Tombe of Belfast College of Technology, another argument is presented for space having at least one innate characteristic, which he suggests is 'polarization', or paired poles.

Maxwell's displacement cur-

rent is introduced in modern textbooks using the following argument.

Ampere's circuital law can be written:

$$\text{curl } \underline{B} = \frac{4\pi}{c} \underline{J} \quad (1)$$

$$\text{div curl } \underline{B} = \frac{4\pi}{c} \text{div } \underline{J} \quad (2)$$

Since the div of a curl is always zero, we arrive at

$$\text{div } \underline{J} = 0 \quad (3)$$

But the equation of continuity states that

$$\text{div } \underline{J} = -\frac{\delta \rho}{\delta t} \quad (4)$$

This dilemma results in the conclusion that equation (1) only holds for static situations and that a modification is required for time

varying B fields. The additional modification term must be such that

$$\begin{aligned} &\text{div (the additional term)} \\ &= + \frac{\delta \rho}{\delta t} \end{aligned} \quad (5)$$

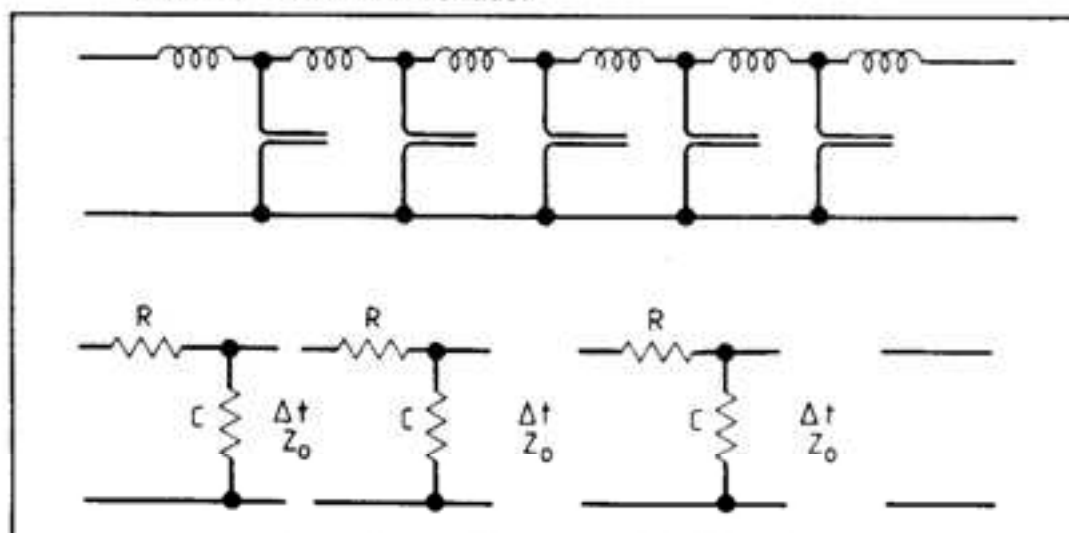
so as to always cancel out with $\text{div } \underline{J}$. The result is that the 'displacement current' is added on and the equation now looks like this;

$$\text{curl } \underline{B} = \frac{4\pi}{c} \underline{J} + \frac{1}{c} \frac{\delta \underline{E}}{\delta t} \quad (6)$$

But this extra term must surely contradict the original derivation of equation (1), since taking the curl (spatial differentiation) has no relevance to the time dependent aspect of B .

The 'displacement current' can in fact be justified another way simply by viewing it is a

Fig.10. Old (1) and new (b) models for lossless line.



polarisation current component implicit in the original \underline{I} term. If we define the vector \underline{D} , having direction of current, such that

$$\underline{I} = \frac{\delta \underline{D}}{\delta t} \quad (7)$$

Then

$$\text{div } \underline{I} = \frac{\delta}{\delta t} (\text{div } \underline{D}) \quad (8)$$

From the equation of continuity

$$-\frac{\delta \rho}{\delta t} = \frac{\delta}{\delta t} (\text{div } \underline{D}) \quad (9)$$

therefore, integrating, we get

$$\begin{aligned} & -e + \text{constant} \\ & = \text{div } \underline{D} \end{aligned} \quad (10)$$

Now

$$\text{div } \underline{E} = 4\pi\rho (\text{Gauss's Law}) \quad (11)$$

Combining (10) and (11) we see that

$$\underline{D} = -\frac{\underline{E}}{4\pi} + \underline{D}_2 \quad (12)$$

Hence using (1) and (7),

$$\underline{I} = \frac{\delta \underline{D}_2}{\delta t} - \frac{1}{4\pi} \frac{\delta \underline{E}}{\delta t} \quad (13)$$

$$\text{curl } \underline{B} = \frac{4\pi}{C} \underline{I}_2 - \frac{1}{C} \frac{\delta \underline{E}}{\delta t} \quad (14)$$

Such a derivation implies that electromagnetic waves cannot possibly exist in the absence of a medium in which polarisation is linked to displacement current. The minus sign means that the displacement current is in the opposite direction to the opposing electric field caused by the linear ether stress of polarisation. This is identical in principle to Lenz's Law for torsional aether stress which occurs in Faraday's Law.

TEM wave

The conventional wisdom on electromagnetism contains two mutually contradictory versions of the Transverse Electromagnetic Wave. The first, the Rolling Wave, is the view of 90% of academics. Opposed to this view, the second, correct version, called the Heaviside Signal, attracts the remaining 10% of academics. It is remarkable that the contradiction has never been noticed²⁴.

Rolling Wave. Kip²⁵ describes the Rolling Wave;

"...Our demonstration involves the use of the first two Maxwell equations to show that such a postulated time and space variation of \underline{E} gives rise to a similar time and space variation of \underline{H} (but at right angles to \underline{E}) and that this \underline{H} variation cuts back to cause the postulated variation in \underline{E} . Thus, once such a wave is initiated, it is self-propagating."

The two relevant Maxwell Equations are

$$\frac{\delta \underline{E}}{\delta x} = -\frac{\delta \underline{B}}{\delta t} \text{ and } \frac{\delta \underline{H}}{\delta x} = -\frac{\delta \underline{D}}{\delta t}$$

Heaviside Signal. Opposed to the Rolling Wave is what we shall call the Heaviside Signal. The most highly developed form of this view is that at any point in space, an electromagnetic signal always contains one kind of energy only. The energy density is equal to the product of \underline{D} and \underline{B} at that point. The rate of flow of energy, which travels at the speed of light \odot , through unit area is

equal to the product of E and H at that point. E , H and \odot are always mutually perpendicular. $E/H = \sqrt{\mu/k}$ and $\odot = 1/\sqrt{\mu k}$. There is no interaction between E and H , which are co-existent, co-substantial, co-eternal³.

Beyond Theory H

For the last century, the lost debate in electromagnetic theory as between Theory N (Fig.1), that current and charge in/on wires cause fields, and Theory H (Fig.2) that the electromagnetic field travelling down between two conductors is the cause and electric current and charge in the wires are effect of that cause. I call the debate 'lost' because some 70 years ago the wrong theory, Theory N, won the debate and suppressed all evidence of the existence of the (energy current) alternative, Theory H. (The recent assertion of Prof. Ziman FRS, that 'The aim of science is to achieve consensus' gives the seal of approval to this suppression.)

Fundamental to all three theories, N, H and C, is the principle of conservation of energy. The measure of energy flow is the electromagnetic field $E \times H$ (i.e. the Poynting Vector). In the case of Theory N, the current and charge in the wires cause the field, which field transports the energy. A theory which is energy based must retain the energy carrier, $E \times H$. It must also retain the cause of the energy carrier, i and \mathcal{Q} . In the case of Theory H, the energy carrier $E \times H$ is the cause, and i and \mathcal{Q} , being secondary

effects of that cause, are not essential to the transport of energy. Heaviside failed to notice that in Theory H, i and \mathcal{Q} were outside the path of the theory from (a) prime mover $E \times H$ to (b) effect, the flow of energy. He never questioned the need for i and \mathcal{Q} in his revolutionary Theory H.

Although the Catt Anomaly was discovered after Theory C, it shows us that major problems arise when electric charge tries to play its part properly in the passage of TEM wave guided between two conductors. The way out of the dilemma is to excise i and \mathcal{Q} from Theory H, leaving us with a non-dualistic theory, Theory C.

Theory C

In 1873 Maxwell wrote²⁶

"Since ...the theory of direct action at a distance is mathematically identical with that of action by means of a medium, the actual phenomena may be explained by the one theory as well as by the other, provided suitable hypotheses be introduced when any difficulty occurs."

This statement led Hertz to say, "Maxwell's Theory is Maxwell's set of equations."

If we allow ourselves Maxwell's extraordinary licence, we find that Theory C is also Maxwell's Theory. Even though in Theory C, charge and current have been excised from the theory of a TEM wave propagating down between two conductors,

Maxwell's Equations still serve us by making us able to manufacture instruments, *i* and *e*, since they have been found to be useful constructs in the past, although now they lack physical reality (in the say way as acceleration lacks physical reality, being merely a mathematical manipulation of physically real distance and physically real time).

Numerous well known (but very confusing) theoretical bodies of knowledge are transformed by the change of view caused by Theory C. In the case of a transistor or thermionic valve, the problem is no longer one of how the charge (electrons) travels from emitter (cathode) to collector (anode). Now, all movement is in a different direction. Energy current, guided by the two conductors, (Fig.11), enters sideways into the critical interface between emitter (cathode) and base (grid), gradually accumulating as it vacillates to and fro along the junction. After a time, the density of the energy reaches a critical value (0.7V) and this causes other energy current, travelling towards the transistor (valve) guided between the emitter wire and the collector wire, to see a shot circuit (instead of the earlier open circuit) by when it reaches the far side of the component. Whereas before, the incident energy current arriving between emitter and collector wires reflected without inversion, it is now inverted before it reflects back towards the +5V supply. Electric charge is not involved — it would collide with the Catt Anomaly.

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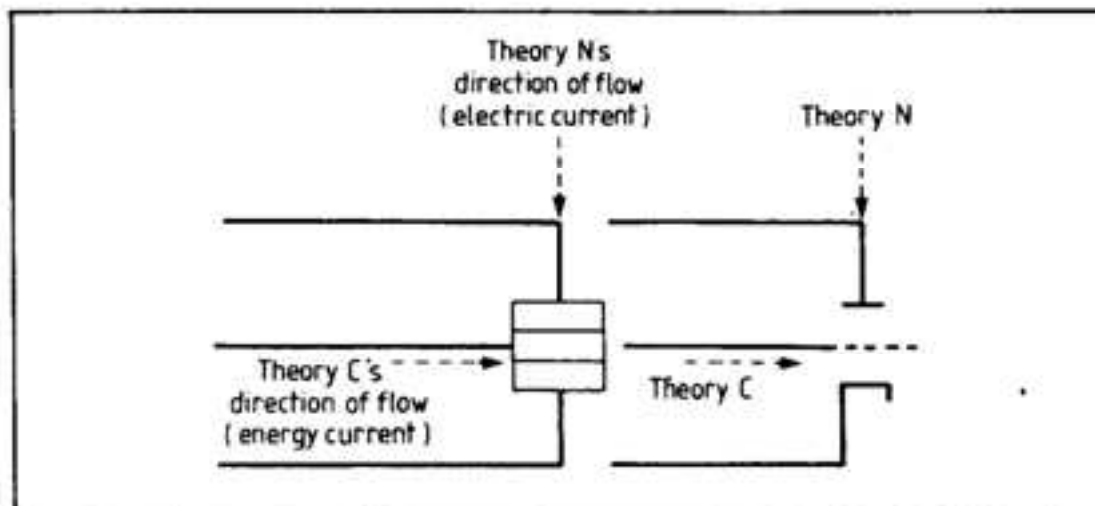


Fig.11. Theory C turns e.m. through 90°.

ENERGY TRANSFER

ELECTRONICS & WIRELESS WORLD NOVEMBER 1984

Once more *Wireless World* gives space to Ivor Catt's views on EM theory. It would help his efforts to overthrow the current position (the 'establishment view') if he showed more evidence that he knew what it was.

His article in the September issue of WW contains at least six major errors, any one of which is sufficient to destroy his thesis.

- Sinusoids and pulses are convenient ways of analysing waves mathematically, be they electric, water or acoustic. The 'mistake' attributed Einstein and 'the modern physics community' just cannot exist.

- He constantly confuses impedance and resistance, leaving his transmission line analysis without value. EM energy is turned into heat by a resistance. When flowing in a transmission line or free space the energy is not changed into heat by the impedance but can be fully recovered as electrical energy. It is rubbish to say that modern physics ignores the impedance of free space, antenna theory and practice is based on it.

- He persists with his view that modern physics somehow requires electric charge to move with the speed of light in conductors. This is nonsense. It is helpful to regard a conductor as a pipe full of water, water flows in one end and out the other when pressure is applied. Naturally water flow is not the same as charge flow but those 'disciplined in the art' do not think, as Mr Catt would have us believe, that electrons have to rattle down some empty tube of a conductor, filling it up at the speed of light. A conductor already has lots of free electrons in it, all ready to start moving under the influence of a passing wave, it is this that distinguishes it from an insulator.

- He carries his conception of a capacitor as transmission line only so far and fails to complete the analysis. He shows it as an unterminated transmission line, but an open line is always terminated by free space with an approximate impedance of 377 ohms so every time a pulse travels down the line some

energy is radiated and some reflected. Ivor Catt's mistake is to imagine that there can be some sort of permanent wave oscillating back and forth. Capacitors (and inductors) are only approximations, there can be no exact analysis of a capacitor without including inductive, resistive and transmission line effects. It is worth noting that it is a common v.h.f. and u.h.f. technique to use a transmission line to approximate a capacitor or an inductor.

D.J.O. Reilly

Antwerp

Belgium

Reference the "Catt Anomaly", there is no anomaly to thoroughgoing Practising Electrician who really believes in charges, currents and fields, since to him it is obvious that a conductor is not just an empty tube. Space does not guide a TEM wave, and intrinsic semiconductors do not either and suffer from space charge effects etc. Conductors are materials that have a high density of mobile carriers, far in excess of the induced charge that moves at "the speed of light". There is no reason why a charge should not move at the speed of light or even more. A

charge is a local imbalance between the two polarities of particle. An electric current is the slow drift of the mobile ones. Consequently, where the drift velocity changes, there is a charge build up. The location of a charge can therefore be changed at any geometrical velocity. (A location is neither mass nor signal — thus keeping relativity happy.) Since the drifts are caused by the penetration of the external fields of the TEM wave, the actual velocity with which the drifts rearrange themselves is limited to the phase velocity of the TEM wave with the prevailing boundary conditions. In the case of a step pulse the drifting region elongates at the propagation velocity (nominally c), whilst charge pours into the moving transition region where the drifting carriers "collide" with the stationary ones. As it sweeps along, it leaves the surplus charge behind as a region of enhancement. Where does the charge come from? Nowhere. It was there all the

time. All that has happened is a slight compression of the carrier density, made up at the driving end by the earth return current.

D.H. Potter

Axminster

Devon

Ivor Catt implies yet again that it is impossible for those "disciplined in the art" of conventional electromagnetic theory to understand the propagation of a current-voltage pulse or step along a twin conductor transmission line. Specifically he implies that the rapid progress of the two electrically charged zones along the conductors, terminating the electric lines of force looped between them, cannot be accounted for ("the Catt anomaly"), since the drift velocity of conduction electrons in metals is known to be small compared with the speed of light.

The conductors and the surrounding fields represent intimately coupled systems, both essential in the type of transmission system described by Catt. According to the elementary theory of metals the conduction electrons in a circuit behave much as the molecules of a gas contained in a loop of pipe. The current source, such as a cell, behaves as a circulation pump for the gas, sucking electrons in at the positive pole and ejecting them at the negative pole. The metal also contains positive ions, equivalent to obstructions in the pipe, and due to the associated frictional effects (equivalent to resistivity on the metal) the gas

can indeed only be circulated at comparatively low speed. Catt continually overlooks the fact that variations in electron gas pressure and density generated by the electron pump may be propagated much faster, in the same way as sound propagates through air or a train of coupled wagons quickly jerk successively into motion when the locomotive pushes or pulls them. The zone with increased density generated, say, by a compression stroke of a pump extends to a range equal to the velocity of sound multiplied by the stroke duration. It is this principle which allows a loudspeaker to generate wavelengths much longer than the amplitude of vibration of the

cone itself. The combination of the rapidly moving fluctuations in electron gas density and the background of positive ion charge yields the necessary, rapidly moving positively or negatively charged zones in the metal. The analogy with sound propagation is not quite exact, since the extra charge prefers to collect on the surface of the metal to reduce energy, much as cream floats to the surface of milk. Also, the electromagnetic interaction between the electrons equivalent to gas pressure or wagons colliding with each other, is transported principally through the

surrounding dielectric medium into which the electromagnetic fields penetrate deeply in lines with typical geometry. In the gas filled pipe analogy this is equivalent to the transport of a signal via the material of the pipe itself, which one generally seeks to minimize in practical acoustics. The speed of propagation of electron density variations is accordingly limited by the speed, and in typical lines the relevant speed is that for the dielectric medium. As Catt states, the energy ultimately delivered to the load is most economically regarded as transported by the fields, the conductors acting essentially as a guide for the energy. Contrary to Catt's claim, libraries well-used by "the modern physics community" contain many texts on the transient response of transmission lines. The authors naturally assume that elementary notions of wave generation etc. were well-assimilated by the reader at an early age, and make little reference to very basic ideas.

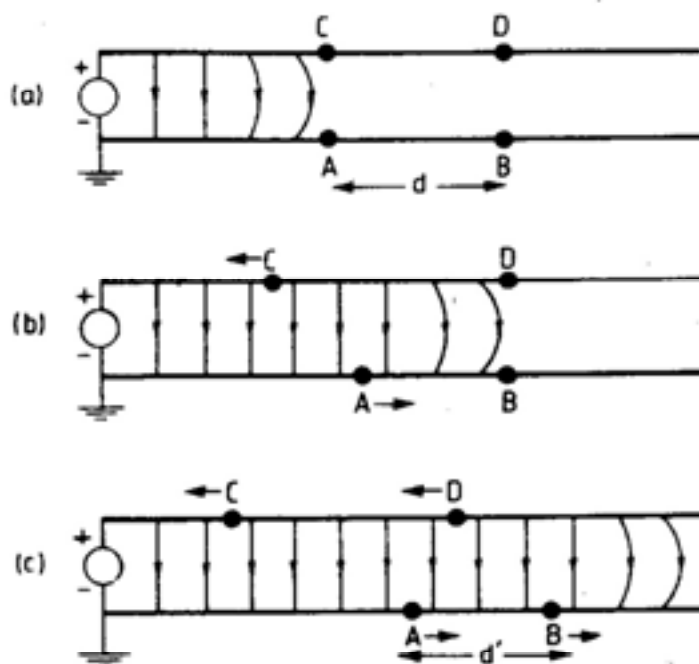
*N. Morton
Stockport*

I would like to make two comments on Mr Catt's article on energy transfer.

First, I remember being taught as an undergraduate about the passage of stepwaves and pulses along a transmission line, as well as sinewaves. That was forty years ago, long before t.t.l. and c.c.l. were dreamed of. Yet we were interested in pulses even in those days (remember when radar was still called radiolocation?). So perhaps it would be unwise to assume that everybody else has been taught as badly as, apparently, was Mr Catt.

Second, the Catt anomaly, the details of what happens when a step-wave passes along a transmission line, need more discussion than perhaps Mr Catt felt able to give them in a short article. The figure shows a step-wave passing from left to right. In (a) it has not yet reached two electrons A and B in the earthy wire, which are still at rest a distance d apart. The electric field at the wavefront is bowed outwards, convex in the direction of motion (remember that "lines of force" are supposed to repel each other sideways). Hence at the surfaces of the wires there are components of the field along the wires. Therefore when the wavefront passes electron A the

Fig.1



latter experiences a momentary force (an impulse) which sets it moving relatively slowly — drifting — along the wire. In (b) is shown the situation when the wavefront has passed A, but has not yet reached B. On a truly loss-free system A does not need any further force to keep it moving, so behind the wavefront the electric field is strictly normal to the wires. The important point to notice is that the distance between A and B is decreasing.

In (c) the wavefront has passed B also. B has been set moving, with the same velocity as A, so the pair of electrons drift along together, with a constant but smaller distance d' between them. Applying this result to all electrons in the earthy wire it appears that the moving electrons everywhere behind the wavefront are slightly more crowded together than when they are at rest.

Hence in unit length of the wire there is a larger number of negatively charged electrons than the number of positively charged ions in the parent atoms fixed in the wire. That is, the wire has (as expected) acquired a net negative charge on which the "lines of force" terminate. Conversely, in the live wire the passage of the wavefront causes electrons such as C and D to drift to the left, with an increase in the distance between them. In this wire the mobile (conduction) electrons are less crowded together than normal, and there is a net positive charge from which the "lines of force" originate. To sum up, if in a wire (any wire) the flow of (electron) current is in the same direction as the flow of energy then the electrons are more crowded together than normal; if in the opposite direction, the electrons are less crowded together. This is a detail in the description of the flow of current which admittedly few text books mention.

Nowhere in the foregoing argument has it been demanded that any electron should move with the velocity of light; yet the accumulation of charges, positive and negative, keeps pace with the travelling wavefront. This is because the

accumulation are formed by the wavefront itself, from the electrons which are already present at the wavefront. The Catt anomaly does not exist, so any arguments which are adduced to 'explain' it are unnecessary.

In practice the crowding is, relatively, very small. Consider an air-spaced transmission line of characteristic impedance

50Ω, so that its capacitance is (very nearly) 20 pF/ft. For a step wave of amplitude 1V the net charges, negative and positive, are 20pC/ft.

Dividing this by the charge on an electron, $1.6 \times 10^{-19} \text{C}$, we find that number of excess electrons (or holes) is $1.25 \times 10^8/\text{ft}$. But this is small compared with the number of conduction electrons which in a metal is about 10^{23} per cc. If the wire of which the line is made is 1mm in diameter its volume is 0.24cc/ft, so the relative excess or deficit is $(1.25 \times 10^8)/(0.24 \times 10^{23}) = 5.2 \times 10^{-15}$. This number is so small that Mr Catt, and possibly many other people, may be forgiven for overlooking it.

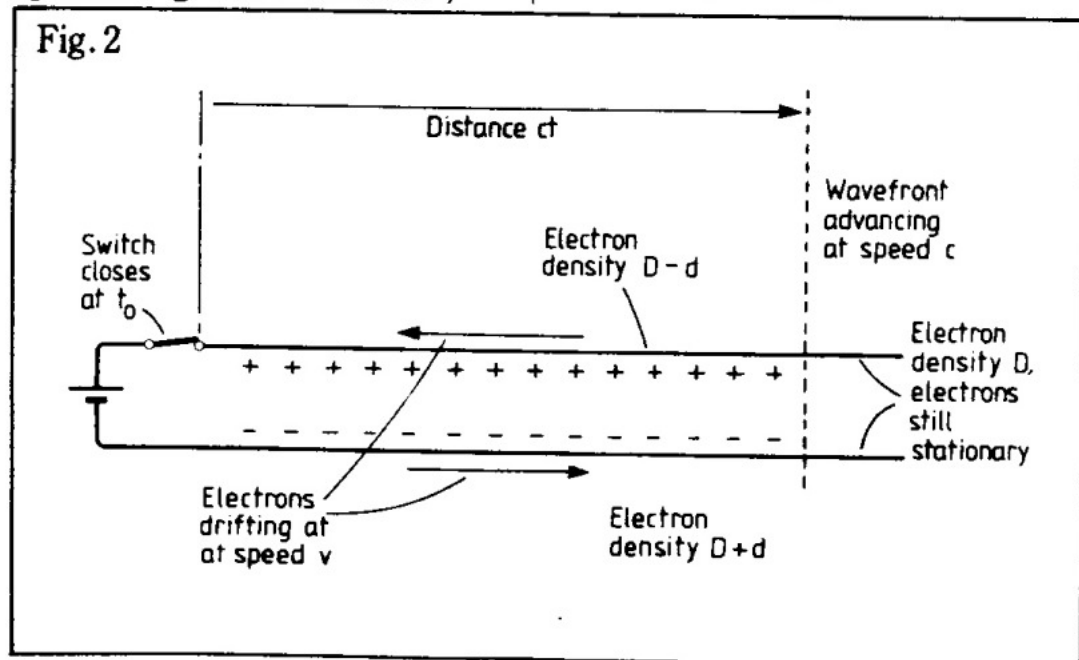
*P.L. Taylor
Marple
Chehire*

Ivor Catt seems to have repeated a misconception about what happens in transmission lines.

Fig. 2 shows the state of affairs in a transmission line after a voltage step has been applied to its left end. The switch was closed at time t_0 , and after a further time t , the wavefront has advanced a distance ct , c being the speed of TEM propagation in the dielectric. The left of the wavefront there is an excess of electrons on the lower conductor and a shortage on the top conductor. The right of the wavefront there is no net charge on the conductors. Concentrating on the lower conductor, Catt wants to know where the excess of electrons came from. "Not from somewhere on the left", he says, "because such charge would have to travel at the speed of light in a vacuum",

and that this "is obvious to the untutored mind." It is fairly obvious to my untutored mind that somewhere on the left is exactly where the charge came from, that there is absolutely no need for it to travel at anything like to speed of light, and that Catt is wrong.

Perhaps I can illustrate by way of analogy. Imagine a row of coins, all 25mm in diameter, and each separated from the next by 1mm. I begin to push the leftmost coin to the right at 1mm per second. After one second it touches the next coin and this begins to move. After another second this bumps into the third coin. This contact happens 26mm to the right of the first, one second later. After each second elapses, another contact occurs 26mm to the right of the previous one. We can imagine this sequence of contacts to be a "wavefront" running through the coins at



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26mm per second — that is 26 times the speed of the coins themselves. To the right of the wavefront there is one coin every 26mm, but to the left there is a higher “coin density” of one every 25mm.

Returning to the bottom conductor, electrons to the right of the wavefront have the “neutral” density D , but to the left they have a slightly excess density and are drifting slowly to the right. The wavefront itself is moving at the speed of light. Obviously electrons do not “bump into” one another like coins, but the principle is the same. To a first approximation the ratio of c to v is the same as the ratio of D to λ .

In a real transmission line the “neutral” electron density D depends on the geometry of the line and the type of conductor material used. V and λ also depend on these factors, and on the size of the voltage step applied as well. The velocity of propagation of the wavefront though, depends only on the dielectric and has something pretty fundamental about it — which to my mind gives credence to the idea that energy

flows through the “insulator”, and not the “conductor” which is in fact a barrier to energy flow. After all, metals are shiny because light bounces off them, and I can’t ever remember seeing the wires that carry the sun’s energy through space to us. I wish Catt would not discredit such (at least potentially) good ideas by throwing in duds of this own.

One final point. On page 47 Catt says “The fact that parallel voltage planes, when entered at a point, present a resistive, not reactive, impedance, was for me an important breakthrough”. Really? If a disturbance is applied at a point in such a pair of planes, a circular wavefront will propagate away from the point. As it moves out, its size will increase, and the impedance of the planes to the wavefront will fall.

As a result of this, energy will be reflected back to the original point of disturbance. This continuous reflection process will present to the disturbance an inductive impedance — won’t it?

Alan Robinson
London

FUNDAMENTALS OF ENERGY TRANSFER

It is always refreshing to see a contribution from Ivor Catt even if I do not wholly concur with his conclusions. I am well aware

of Heaviside's views that electromagnetic energy leaves a source and enters a load sideways, and he gives an example of a source in London connected by a telegraph wire to a receiver in Edinburgh. Some of the energy from London travels far out into space before converging on the receiver,, but unfortunately I have not been able to find in Heaviside's Electromagnetic Papers any account of how the energy in distant space knows that it is time to start the descent for Edinburgh. However, this is a difficult matter and it is not surprising that the story is incomplete. What is much more difficult to accept is why we should in our theory stumble on the relatively simple matter of a parallel-wire transmission line.

The National Physical Laboratory defines the SI unit of electric current as "The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible cross

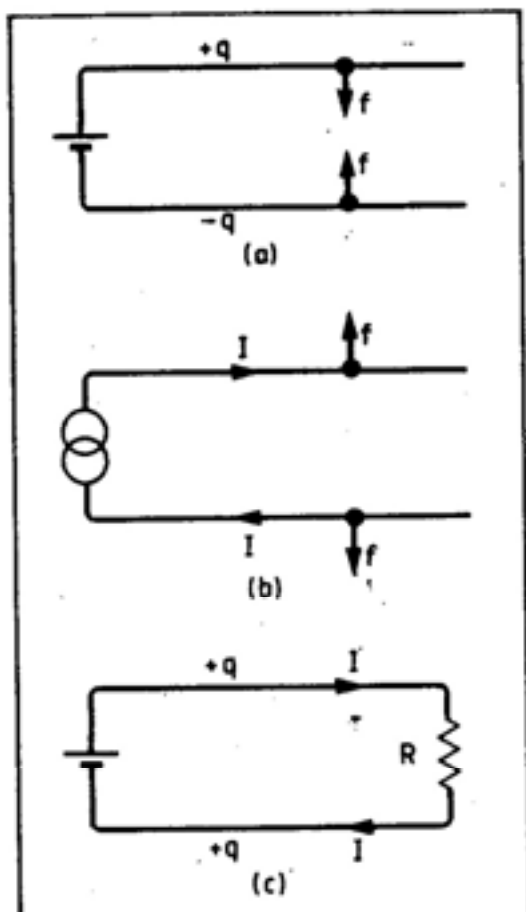
section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newtons per metre of length."

Many text books on electricity, elementary and advanced, use similar wording to define the ampere and indeed the definition is not new. If we substitute centimetre for metre and dyne for newton we have the c.g.s. electrodynamic definition of the ampere that has been used since the beginning of this century, and during this time this piece of scientific nonsense has been for the most part uncritically accepted.

Consider the following relatively short transmission lines:

In diagram (a) the line is open circuit at the distant end hence the conductors experience a mutual electrostatic attraction. In (b) the conductors carry a current and hence mutually repel each other. In (c) we have a combination of electrostatic attraction and electromagnetic repulsion which for some value of R must neutralise each other.

Not very surprisingly the value of R to produce zero resultant force is the characteristic impedance of the line, and that can be achieved by extending the line in diagram (a) infinitely to the right. It seems to have been forgotten



that if a line has $Z_0 = 100\Omega$ then to establish a current of 1A in the line we need a supply of 100V and the electrostatic attraction because of that cannot be ignored.

Forces on the conductors of a transmission line arise from reflections, and the principal characteristic of an infinite line is that it is free of reflections. Now this absence of force on an infinite line follows almost intuitively from the principal of virtual work so it is all the more surprising that the error should have gone undetected for so long. In an infinite line there is equal sharing of the stored energy between the electric and magnetic fields associated with the line. If we increase the

separation of the line conductors by a small amount we need a force to overcome the electrostatic attraction, and that can be calculated from $f = dw/dx$ where dw is the increase in stored energy and dx the displacement. Likewise the force associated with increasing the magnetic field energy is $f = dw/dx$ and because of energy sharing equally, dw is the same in each case, as is dx , and the forces oppose each other, so there is a net resultant of zero. Mr Catt rightly says that nothing travels sideways across a transmission line in the TEM mode and that includes force. Lateral forces on the conductors of a transmission line always arise because of reflections that upset the balance of electric and magnetic energy storage in the line. That is only possible with a line of finite length.

Of course it may be objected

that the definition does not specify that the two conductors should be the go and return of a single circuit. They could perhaps be the two go conductors of a circuit with a distant common return. Apart from the added complexity due to the third conductor the problem is the same whether the currents in the specified conductors flow in the same or opposite senses. The twin-beam c.r.o. is an example of two parallel conductors carrying current in the same direction. It can be easily shown for this case that for relatively low anode voltages the beams repel each other electrostatically. As

the anode voltage is increased the magnetic attraction of the beams becomes greater and would exactly neutralise the repulsion if the electrons in the beams could accelerate to the speed of light and there, as in the case of infinite parallel conductors, the net force would be zero. Examination questions on this part of c.r.t. science are not uncommon and take the form of "Show that, no matter how the beam electrons are accelerated, the force between beams can never become attractive". The short answer to that is that we can never get the electron velocity up to the energy propagation velocity of the parallel conductors.

It is quite understandable how the definition of the ampere comes to be as it is. A line of finite length has end effects that we do not know how to take into account, so what could be simpler than to remove them to infinity? Unfortunately this ploy leaves us with a useless line as far as the measurement of force is concerned.

In practice, the SI definition makes no difference for no one pays any attention to it. The ampere is standardised using an Ayrton-Jones current balance in which the conductors are arranged as circular coils and not as straight lines. In the Ayrton-Jones balance we are dealing with equivalent lines finite length short-circuited at the far end so that all the energy is stored in the magnetic field and none in the electric field, so we have no problems.

However, the definition does make a difference of those of us like Mr Catt and me who have some responsibility for educating the young in fundamentals of our science. How can Mr Catt

persuade his students that nothing traverses a transmission line in the TEM mode sideways, when in all quarters, they see "authoritative" statements to the contrary?

Chris Parton
Bell College of Technology
Hamilton
Scotland

Mr Catt's article (September 1984) treads some very shaky ground: I consider many of his statements to be rather questionable but I think I can lay the rest the so called 'Catt Anomaly'.

If I understand Mr Catt correctly he is unwilling to accept that a charge pulse can travel down a transmission line at a speed greater than the speed of light local of the copper of the conductors.

In fact, the speed of light in the conductors (or, for that matter, the electron drift speed of some millimetres a minute) has no bearing at all on the speed of an EM pulse travelling down the transmission line. In 1 nanosecond charge does not have to travel 1 foot down the wire: all that is required is for a drift of charges to occur at the leading edge of the pulse, as it moves, so as to leave a net charge on the wire, in the wake of the pulse.

If this does not seem clear, consider the case of a low amplitude sound pressure pulse, travelling down a pipe: the air in the pipe, behind the wavefront travels very slowly indeed, while the pressure front travels forwards at the speed of sound.

I should like to add that I consider the issue of whether EM fields in a waveguide cause currents in the conductors, or vice versa, to be a meaningless, unanswerable question: field and currents are related by the physics of the situation, one does not precede the other in time, and no wave or pulse travels without both.

There are a great many statements in Mr Catt's article to which I take exception, but I lack the enthusiasm to describe all the fallacies, or research his reference list to isolate their origins.

N:C. Hawkes
Abingdon
Oxfordshire

DISPLACEMENT CURRENT

Maxwell's displacement current provides a physical mechanism for the thermodynamic concept of entropy.

When a capacitor is connected across (strongly coupled with) an e.m.f. the microscopic electronic configuration of the circuit changes as charges are re-distributed around the circuit. The 'information' that any changes in (relative) position of the microscopic elements has occurred propagates out at a finite speed to ('communicates with') distant space (entropy losses), which constitutes the loosely coupled environment (Mach's principle). In other words, the circuit scatters energy to space when it is closely coupled to the e.m.f.

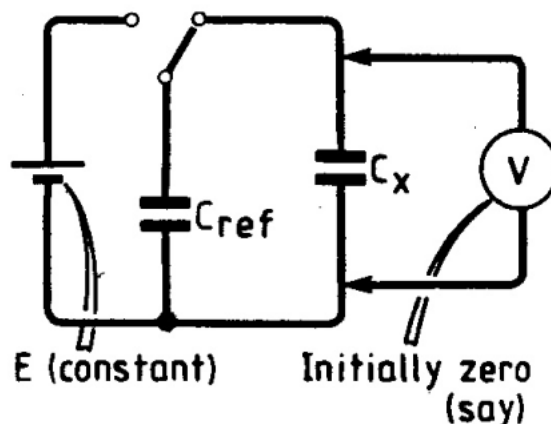
Consider the problem of bucket charge transfer from a virtually infinite source to a finite reservoir

On each cycle of the changeover switch C_{ref} charges to a constant

voltage E then shares its charge with the (unknown, say) capacitance C_x . On each switching contact there is energy loss (or 'taxation') from the circuit. It is elementary to calculate the voltage on C_x after n switchings and obtain the asymptotic solution (sent to WW Editor in 1982, I believe, and dramatically forgotten as of no significance to the theoretical real world).

How does Mr Catt's theory, based on its fundamental causal concept of 'energy' (whatever that really is), and, no doubt, on the principle of its conservation within any electrical system, account for entropy losses?

P.J. Ratcliffe
Stevenage
Herts



ENERGY TRANSFER

My article in *Wireless World*, September 1984, entitled Fundamentals of Electromagnetic Energy Transfer led to a large number of comments being published in the November issue.

D.J.O'Reilly complained about my confusing impedance and resistance, "...leaving (my) transmission line analysis without value."

I have for long thought that use of the term 'characteristic impedance' for a transmission line is misleading — it certainly is for a lossless line, because the word "impedance" implies a combination of resistance and reactance, (see for instance "Advanced Physics" by S.M. Geddes, pub. Macmillan 1981,

page 189,) whereas a lossless transmission line contains no reactance. It is for this reason that for many years I have wanted to use the term 'characteristic resistance'. (Also note in *Wireless World* Oct, 1984, page 50, the criticism of the repeated LC model for a transmission line. The idea that a transmission line contains alternate L and C is false and destructive.)

When O'Reilly writes, "It is rubbish to say that modern physics ignores the impedance of free space, antenna theory and practice is based on it," he ignores the distinction made earlier in the article between

'modern physics' and digital electronics. Under such classification, antenna theory would certainly not fall within modern physics. Ask modern physics pundits, for instance Professor Paul Davies of Newcastle University or Nobel Prizewinner A.Salam of Imperial College whether they have studied antenna theory. O'Reilly is surely not disputing my point, that modern science is seriously fragmented. No comment on Messrs. Potter and Morton. Whatever lecturer or text book taught P.L. Taylor that "...the wavefront is bowed outwards, convex...", i.e. that a TEM wave is not TEM? Certainly not Heaviside, see refs. 2 and 3 in my September article.

I agree with Alan Robinson that if a conductor were filled with a row of rigid electrons touching each other, simulating a rigid rod, then an effect could travel at infinite speed even if the electrons (= rigid rod) travelled slowly. This has nothing to do with the theory of the TEM wave, at least as discussed heretofore. Is Robinson inventing the 25mm — 26mm scenario, or will he give us its pedigree?

Referring to Robinson's final point. At the diameter of the wires entering the capacitor, the characteristic impedance of the pair of parallel plates is already very small, and is resistive not inductive. Any reflections resulting from the mechanism he mentions, of a semi-circular flowing out from the entry point

to the two plates, can only serve to reduce an already low resistance. This effect does not correlate with the traditional values of series inductance

alleged to be contained within capacitors, (and which are actually a function of something outside the capacitor - its legs;) which are orders of magnitude larger. Robinson has introduced a high quality red herring.

Ivor Catt
St Albans
Hertfordshire

In considering what Ivor Catt has to say, one has, I think, on the one hand to be aware of the situation that existed between the Church and Galileo.

Although his findings were of the utmost significance to the world in the end, he was a heretic for propounding them. But on the other hand one is tempted to think that it is just possible that Mr Catt is learning as he goes; that I shall not condemn. After all, this was the great genius of Michael Faraday, noticing happenings he was not in the process of seeking, and then following them up. But one has to be so careful of mistaking what one is learning as one goes, for discovery.

I have been poking pulses out of sources to distant destinations since 1924,

whether on wires, down tubes, or just plain flying off into space. And thought processes that have occurred on the way are related to the most incredible mental gymnastics. As early as 1919, when I constructed my first radio set having a valve, a huge affair with massive oak ends for the loose coupler (about 2ft long) at a time of relatively low-frequency operation, I wondered what would happen if wavelengths ever became shorter than the dimension of the tuning condenser. Would the charge get to the outer edge of the plate, before reversal took place and it was on its way out again. I now know that in fact it would have been an untruncated line of non-classic shape. This was to help me in later life, when it came to the contriving of broad-band aerial systems.

Then again, in my mind I would slow down the velocity of a dot on its way over the single-wire telegraph poles, in imagination keeping up with it on my bicycle, waiting for the other dot which had just left the other end. What, I thought, is to be the nature of the collision if the dots are of like polarity? Or the merger if they are unlike? Now that I am very old, using this slowed down technique, I now have a very fair non-mathematical mental image of what goes on.

But the arrival of Ivor Catt on the scene has set me off again. Take the case of a battery of steady e.m.f. connected to an unterminated line. Wait for the reflections to be absorbed in line resistance, and of course we then have a charged condenser, but no magnetic field in evidence. Now, attempt to change the state of that charge by any means you care to employ, and what have you while charge value is being changed? Why, a magnetic field as long as the state of change exists. It was not there before, so where has it come from. Having charged and stabilised the line, then close it with its characteristic impedance. How does the sending end discern what has happened. One thing that immediately manifests itself is magnetism. Where has it been lurking? Like the heat in unburned fuel. While I have no difficulty in visualising the changes in (dare I use the word) current value when one does this sort of thing, I have not yet got the answer to the appearance and vanishing trick that magnetism can perform. My answer when provided has to be non-mathematical, so visualisation can be communicated. So if Ivor Catt is on the track of this, even by accident, good luck to him.

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 Hurstpierpoint
 West Sussex